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Fabrication of 0.2 μm Fine Patterns Using Optical Projection Lithography with an Oil Immersion Lens

Hiroaki KAWATA, Ippei MATSUMURA, Hitoshi YOSHIDA and Kenji MURATA

Department of Electronics, College of Engineering, University of Osaka Prefecture, Sakai, Osaka 593

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Fine patterns are fabricated by using optical projection lithography with both an oil immersion lens of NA = 1.25 and a conventional single-layer resist. Chlorobenzene soak is used in order to remove the immersion oil and to improve the side wall profile of the resist patterns. Some samples are lightly etched by O_2 plasmas in order to remove a residual resist at the bottom of the resist patterns. Finally, it is found that a 0.18 μm fine resist pattern with a good edge definition can be fabricated. Al line and space pattern with a width of about 0.21 μm is also fabricated by lift-off technique.

KEYWORDS: optical projection lithography, oil immersion lens, NA, chlorobenzene soak, O_2 plasma, lift-off

§1. Introduction

Recently, optical projection lithography has greatly advanced[1] and patterns with a resolution of 0.3 μm can now be fabricated. The resolution limit depends on the value of λ/NA. Therefore, light sources with a short wavelength[2] and/or high-NA lenses[3,4] have been widely investigated in order to improve the resolution.

Since the depth of focus is small when a high NA lens is used, surface imaging processes such as a multilayer resist or a silylation process[5] are preferable. For example, fine patterns with a resolution of about 0.15 μm have been fabricated through use of an oil immersion lens of NA = 1.4 in a previous study,[3] where the trilevel resist process is adopted and an ARC (antireflection coating) film is used as a bottom layer in order to reduce the light reflection effect from a substrate, which is very effective for obtaining fine resist patterns. However, the trilevel resist process is a very complicated process.

In this study, optical projection lithography with an oil immersion lens is performed using a single-layer resist. Chlorobenzene is used in order to remove the immersion oil on the resist surface. It does not attack the resist. Moreover, the chlorobenzene soak can improve the side wall profile of a resist pattern. As a thin resist layer remains at the bottom of the resist pattern under some experimental conditions, the residual resist is etched away by O_2 plasmas. With the fabricated resist pattern, a fine Al pattern fabrication is attempted by lift-off technique.

§2. Experimental

An optical configuration for resist exposure is shown in Fig. 1. The basic optical configuration consists of a commercial optical microscope (Olympus, BHT-2). We additionally provided both a reticle holder and its illumination system, labeled A in the figure. The light source is an Hg lamp of 150 W. Either a yellow or a 404 nm interference filter is placed between the light source and the condenser lens. The reticle is placed at the focal plane of the condenser lens with $f = 35$ mm (so-called Köhler illumination). The filling factor, σ, is fixed at 0.2. Although a larger value of the filling factor is desired, the maximum value is 0.2 in our system. We attempted a resist exposure with a filter of $\lambda = 365$ nm (Hg i-line). However, a sufficient light intensity could not be obtained for the resist exposure. This is probably because the commercial optical microscope is not designed to give sufficient transmission for UV light. The reticle pattern is imaged on the sample surface with an objective lens. We use an oil immersion lens of NA = 1.25 as an objective lens. The exposure light wavelength is 404 nm. The NA value of the objective lens is 1.25. According to these conditions the depth of focus is estimated at about 0.20 μm. Fine focusing is adjusted by a piezo device on which the sample is placed. As the magnified sample image superimposed by the reticle image can be seen by a yellow light

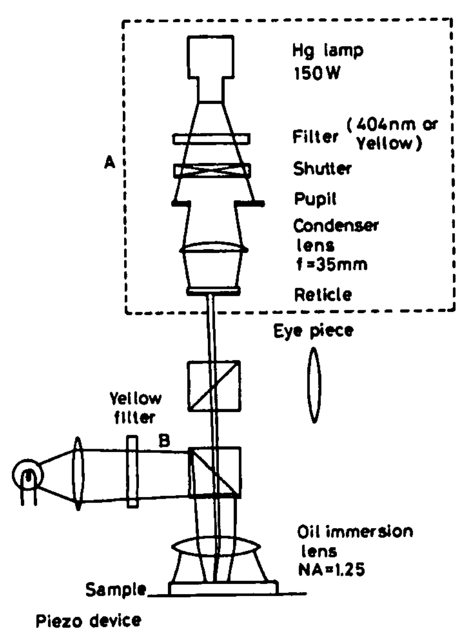

Fig. 1. Schematic view of optical configuration.

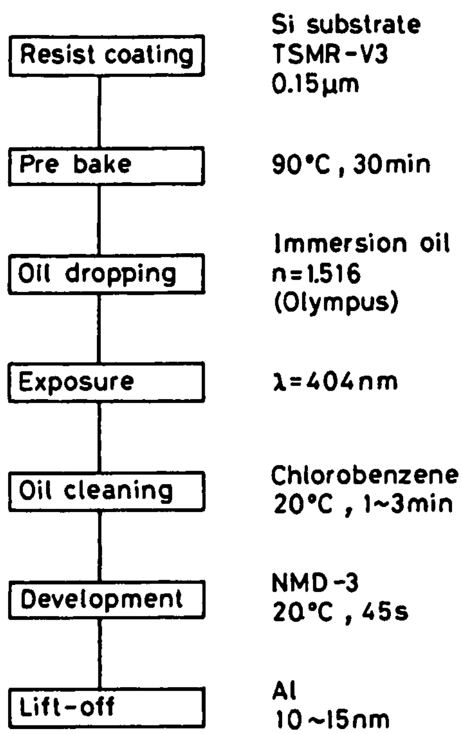

Fig. 2. Flow chart for optical projection lithography using the oil immersion lens.

illumination labeled B in the figure, we can easily find the exposure position.

A brief process flow chart is shown in Fig. 2. A positive photoresist of TSMR-V3 (Tokyo Ohka) is spin-coated on a Si wafer. As the resist thickness should be less than the depth of focus, the resist film thickness is chosen at 0.15 μm. The resist film is prebaked at 90°C for 30 min in a conventional oven. A small amount of immersion oil is dropped on the sample. The immersion oil ($n=1.516$) is available from Olympus. Chlorobenzene is used for removing the immersion oil in our experiment. Chlorobenzene has often been used to make resist pattern profiles with an overhang shape,[6] and it is wellknown that chlorobenzene does not seriously attack the resist film. Moreover, it is expected that the side wall profile of the resist pattern can be improved by chlorobenzene soak. The resist is developed for 45 s with NMD-3 (Tokyo Ohka) at 20°C after removing the oil. Al lift-off is performed for some samples.

§3. Results and Discussion

First we determined both the demagnification of the projection system and the available exposure field area by comparing the reticle and the resist pattern sizes. The demagnification and the exposure field area were 280× and 50 μm × 50 μm, respectively. Two different patterns were used in the following experiments. One is a single space pattern. The nominal space width, which is obtained from both the reticle pattern size and the demagnification, is 0.19 μm. The other is a line and space pattern. The nominal line and space widths are 0.34 μm and 0.19 μm, respectively.

3.1 *Effects of chlorobenzene soaking time*

An example of fabricated line and space patterns is shown in Fig. 3. Chlorobenzene soaking time is 1 min. The line and space widths are 0.30 μm and 0.23 μm, respectively. A widening of about 0.04 μm from the nominal dimension is observed in the space width. Figure 4 shows the exposure time dependence of the space width in the single space pattern for two different chlorobenzene soaking times. The linewidths are measured with SEM observations. The space width greatly depends on the exposure time. This dependence becomes more significant as the pattern size decreases. However, it is found that fine patterns less than 0.2 μm can be fabricated. The space width with a 1 min chlorobenzene soak is somewhat wider than that with a 2 min chlorobenzene soak. This is probably because the surface development is suppressed by chlorobenzene soak.[7] The cross sectional profiles of the fabricated space patterns are shown in Fig. 5 for soaking times of 1 and 2 min. It is clear that a thin resist layer remains in the space when a fine pattern of about 0.2 μm is fabricated. This is because the development rate is the slowest at the resist

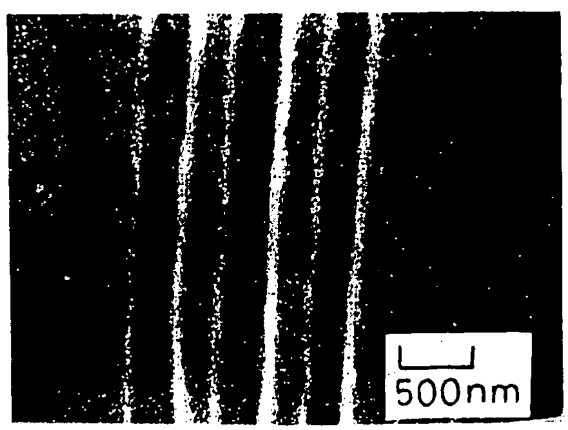

Fig. 3. Example of fabricated line and space patterns. Chlorobenzene soaking time is 1 min.

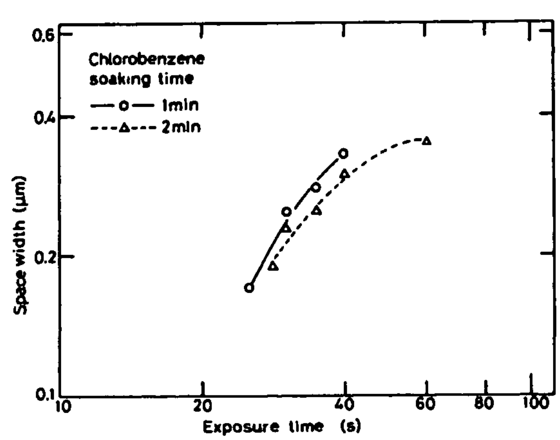

Fig. 4. Space width as a function of exposure time for two different chlorobenzene soaking times when a single space pattern is fabricated.

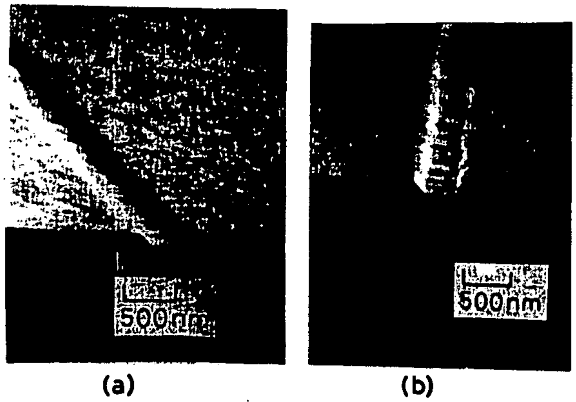

Fig. 5. Cross sections of fabricated space patterns. Chlorobenzene soaking times are (a) 1 min and (b) 2 min.

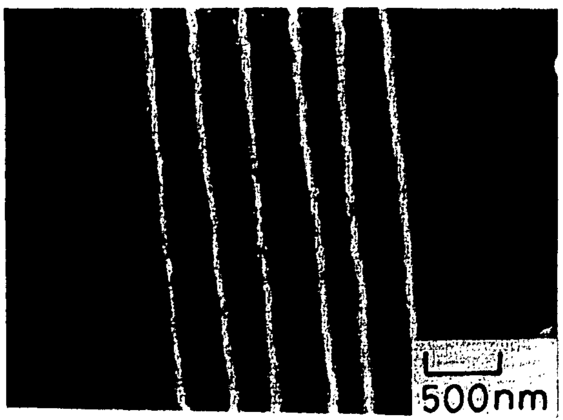

Fig. 6. SEM photograph of line and space patterns for 3 min chlorobenzene soak. The pattern edge definition is clear.

bottom since the light intensity is minimum at the interface between the resist and the Si substrate due to the interference between an incident light and reflected light from the silicon wafer. This effect will be greatly reduced by suppressing reflected light from the substrate by using techniques such as ARC coating.[8] The residual resist should be removed without pattern degradation. O_2 plasmas are used for removing the residual resist. The process will be shown later.

Although neither profile in Fig. 5 is vertical, the profile with a 2 min soak is somewhat steeper than that with a 1 min soak. When chlorobenzene soaking time is increased to 3 min, the SEM micrograph of the fabricated line and space pattern is as shown in Fig. 6. The pattern edge definition is clearer than that in Fig. 3. The side wall profile of the resist pattern with a 3 min soak seems to be better than that with a 1 min soak. Therefore, chlorobenzene soak is effective in improving the side wall profile of the resist pattern in our experiments. It will be necessary in the future to find an optimum time for chlorobenzene soak in order to fabricate a resist pattern with the best side wall profile.

3.2 *O_2 plasma treatment*

Under some experimental conditions the residual resist at the bottom of the resist pattern must be removed without degradation of the pattern profile, as mentioned above. O_2 plasmas are used for this purpose. The plasma chamber used is a conventional parallel plate-type reactor. A wafer is mounted on the powered electrode where the RF power is applied. An O_2+10%Ar gas is introduced to the chamber at a flow rate of 10 ccm. The pressure is about 90 mTorr. The RF frequency is 13.56 MHz. The applied RF power and the self-bias voltage are 40 W and 500 V, respectively. The etching time is about 5 s. The etching depth is as small as 30 nm. The etching mode is classified in the intermediate state between the RIE mode (anisotropic etching) and plasma etching (isotropic etching) in our operating pressure. Therefore, the etching may proceed partially as anisotropic etching. The SEM pictures for a single space pattern are shown in Fig. 7, with and without the O_2 plasma treatment, respectively. For both cases the exposure time and chlorobenzene soaking time are 45 s and 2 min, respectively. Note that the pattern edge definition is improved by the O_2 plasma treatment. Although we cannot confirm the reason for the improvement, anisotropic etching may improve the resist pattern profile. The exposure time dependence of the space width is shown in Fig. 8 for both cases with and without the O_2 plasma treatment. The pattern width increase due to O_2 plasma treatment is more pronounced

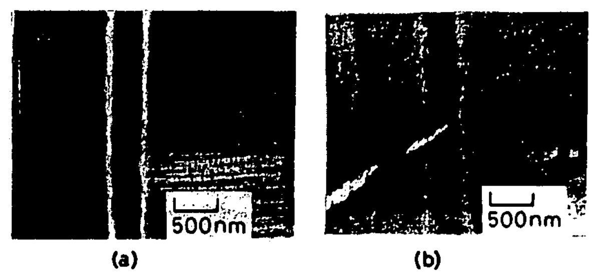

Fig. 7. SEM photographs for a single space pattern (a) with O_2 plasma treatment and (b) without O_2 plasma treatment. Chlorobenzene soaking time is 2 min. The pattern edge definition in (a) is much clearer than that in (b).

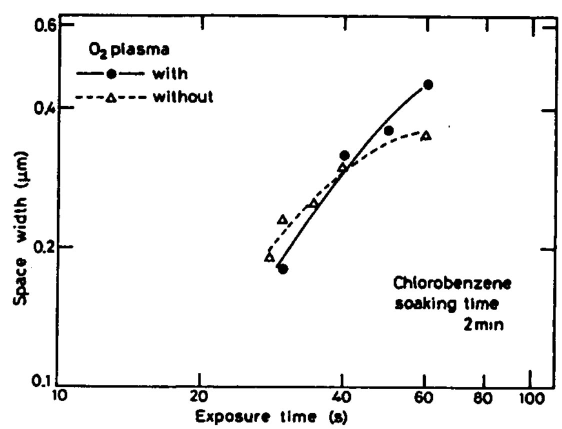

Fig. 8. Space width as a function of exposure time either with or without O_2 plasma treatment when a single space pattern is fabricated. Chlorobenzene soaking time is 2 min.

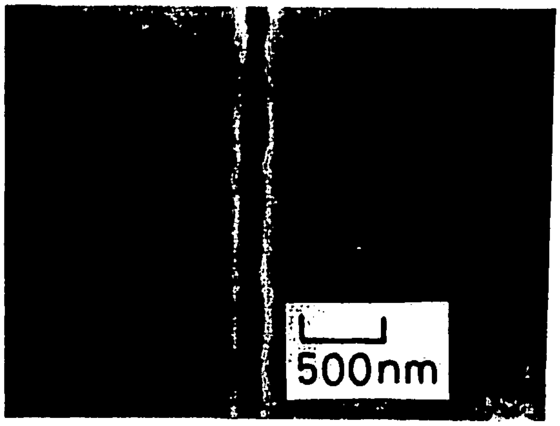

Fig. 9. Single space pattern after O_2 plasma treatment. Pattern width is 0.18 μm.

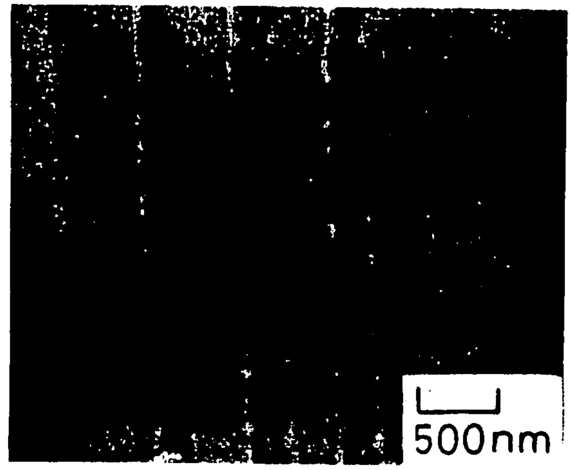

Fig. 10. An Al line pattern fabricated by lift-off. The resist pattern is fabricated without O_2 plasma treatment for a chlorobenzene soak time of 3 min.

with long exposure times. This can be explained in the following way. When the resist is overexposed, the side wall profile of the resist pattern may be degraded; that is, the angle of the side wall may become small. If the same thickness of resist is etched away by the O_2 plasma treatment, the pattern widening is more pronounced for the resist pattern with a small side wall angle. Although the pattern width is always increased by the O_2 plasma treatment, it is somewhat narrower than that without the treatment for short exposure times as seen in Fig. 8. The light intensity may differ between the experiments since we do not precisely control the light intensity. The finest fabricated pattern is shown in Fig. 9 after the O_2 plasma treatment. The pattern width is 0.18 μm and the edge definition is clear.

3.3 *Al lift-off*

Al lift-off is performed using a resist pattern fabricated by the above methods. An Al film of about 15 nm thickness is evaporated on the resist pattern. The Al film is etched by about 2 nm with an etching solution (H_3PO_4:HNO_3:H_2O=10:1:5). This is because if there is a thin Al layer at the side wall of the resist pattern, lift-off will be difficult. The sample is dipped in acetone after the process. When the chlorobenzene soaking time is 1 min, lift-off is not possible at all. When the sample is treated with a 2 min chlorobenzene soak with O_2 plasmas, the lift-off is successful for a single line but not for a line and space pattern. Although the outline of the pattern can be fabricated, the resist between the space patterns cannot be removed. The light intensity must be stronger between the spaces than that at the pattern edge. Therefore, the resist between the spaces is apt to have overexposure and the side wall profile is also worse than that at the edge. When the chlorobenzene soaking time is 3 min, the lift-off is successful for both the single space and the line and space patterns. It should be noted here that the lift-off for this sample is successful even without the O_2 plasma treatment. Figure 10 shows the SEM picture of the fabricated Al pattern. The Al linewidth of the line and space pattern is 0.21 μm. The lift-off is possible only when the side wall profile is steep. Thus, we can make resist patterns with good side wall profiles without use of a multilayer resist system. As we have not done experiments under various experimental conditions, the present lift-off technique may be further improved.

§4. Conclusions

Optical projection lithography is performed using an oil immersion lens with NA=1.25. The sample is a single-layer resist of 0.15 μm thickness on a silicon wafer. Chlorobenzene is used in order to remove the immersion oil. This process is suitable for our experiments, because chlorobenzene does not attack the resist, and the side wall profile of the pattern is improved by the chlorobenzene soak. Although a 0.2 μm fine pattern can be fabricated, a thin resist layer remains at the bottom of the resist under some experimental conditions. The O_2 plasma treatment can remove the residual resist and improve the pattern edge definition. The space pattern of 0.18 μm width can be fabricated with a good edge definition after the O_2 plasma treatment. Also, the Al line patterns are fabricated by the lift-off process. The fabricated Al linewidth is 0.21 μm for the line and space pattern.

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